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Design 50MW large scale PV power plant considering Bangladeshi climate

MD MEHEDI HASAN

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Abstract

Conventional electricity production is undergoing a major transition, and renewable energy projects are playing an important part in this shift. An opportunity exists to use the naturally high solar radiation resource to meet the high electricity demand. This research investigates the design of a PV solar power plant with a capacity of 50 MW which has been modelled on the conditions of Dhaka, Bangladesh.

The PV plant comprises PV modules, mounting structures, inverters, transformers, switching circuits, and DC and AC cables. The calculations of parameters have been done for a specific area with the main objective to ensure the optimal tilt angle for the plant. Then, the performance of the proposed methodology for defined parameters is tested through specialized software 'PVsyst'. Later, the results are compared for different tilt angles to validate the effectiveness of the proposed framework. It is found that the best optimal tilt angle is 25-degree. The projected energy output has been determined to be 82387 MWh per annum with a payback time of 5.5 years and a reduction of CO2 pollution by 1202851.5 tonnes per year for proposed work. Moreover, the calculation methodology used is divided into system design calculations, energy calculations, and assessment parameters calculation. The primary goal of the comprehensive calculations is to obtain the system's Annual Energy Production (AEP). Financial calculations are used to calculate the cost of the PV system as well as the Levelized Cost of Energy (LCOE).

Keywords: Solar energy, solar in Bangladesh, conventional energy, solar irradiation, PV power plant, Tilt angle.

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IMPORTANT TERMS

Solar radiation: The electromagnetic radiation released by the sun is referred to as a solar resource or just sunlight. Using diverse technologies, solar radiation can be collected and converted into usable forms of energy such as heat and electricity.

Direct solar radiation: The solar radiation that travels down the line that connects the receiving surface to the sun. Beam radiation is another name for it. A pyrheliometer is used to measure it.

Global solar radiation: The total of direct and diffuse solar radiation, also known as global radiation. Overall radiation on a horizontal surface is the most common measurement of solar radiation. A pyranometer is used to measure it.

Irradiance: The rate at which radiant energy is received on a surface, per unit area of surface, is known as irradiance.

Performance ratio:

PR is an index that measures the performance of a solar system after considering environmental factors such as temperature, radiation, and climate change.

ABBREVIATIONS

DC – Direct Current
AC – Alternate Current
°C – Degree Celsius
km – Kilometre
kVA – Kilovolt Ampere
kWh – Kilowatt Hour
kWp – Kilo Watt peak
MNRE – Ministry of New and Renewable Energy
MW – Megawatt
MWh – Megawatt Hour
NREL – National Renewable Energy Laboratory
PV – Solar Photovoltaic
V – Voltage
A – Ampere
Wp – Watt peak
SRA – Solar Resource Assessment
AEP – Annual energy production
NPV – Net present value
ROI – Return on Investment
NEC–National Electric Code

Chapter 1

Introduction

Global warming due to greenhouse gas emissions and shortage of fossil fuels has triggered almost all nations in the world to search for an alternative for electricity generation. Renewable energy sources, such as solar, wind, geothermal, and wave energy, are being considered as a substitute because they cause negligible environmental pollution in comparison to fossil-based energy. Whereas developed nations can tap into nuclear energy to meet their demand, growing nations like Bangladesh do not consider this alternative due to its high cost. Consequently, the practical and economical option currently available to Bangladesh is solar energy. Solar energy is becoming a popular source since it is an unlimited supply of energy that helps to reduce greenhouse emissions. [1]

Bangladesh is a semi-tropical country in the north-eastern region of South Asia, where sunshine is abundant all 12 months-round. During the dry season, Bangladesh has an average of 7.6 hours of sunlight each day, while the monsoon season has an average of 4.7 hours. The collection of solar power is free, and one simply needs to invest in required equipment that converts the solar energy to electrical energy through photovoltaics (PV). A PV plant is comprised of one or more solar panels, an inverter, and various electrical and mechanical components. PV systems are available in a wide variety of sizes, from small rooftops or portable systems to huge utility-scale power plants [2]

This project is for the construction of a 50 MW solar photovoltaic power plant using the most recent Thin Film Technology cells. The solar photovoltaic power project is proposed to be set up in Savar, about 15 kilometres south of Dhaka, Bangladesh, and is one of the best locations due to high direct normal insolation (DNI), meteorological conditions, and land availability.

The search for an optimal tilt angle for the design of ground-mounted PV systems is a significant challenge. The increase in the array gap leads to higher annual energy due to the reduction in the Ruder shading effect but increases the costs of land and wiring. Change in the different inclination angle alters the system losses. Therefore, the selection of the best inclination and direction to install modules brings higher energy productivity. Moreover, by finding the optimal tilt angle and distance between the rows, a levelized cost of energy (LCOE) can be obtained. [3] The use of higher efficient technologies is very expensive, but you need a smaller area compared to less effective modules to produce the same amount of energy. It should be noted that the design of PV systems can lead to higher maintenance and loss of revenue due to lower energy production if the initial investment is reduced to save money. Hence, it should be designed with care while considering all the factors.

1.1 Problem formulation

Question: Identify the optimal tilt angle and row spacing for large scale PV power plant considering Bangladeshi climate?

This thesis examines the optimal tilt angle and row spacing used for the deployment of a 50MW solar photovoltaic power plant. Considering all the conditions it is very tough to find out the best tilt angle for a solar power plant in a specific location. Increased array gap results in higher annual energy due to reduced Ruder shading effect but increases the costs of land and wiring.

1.2 Objective of the Project

The objectives for the project are the successful completion of the solar photovoltaic power plant, on budget, on time, and safely. The aim is to design and model the PV plant by implementing the calculation method which is based on the following parameters:

- Find the prospects of solar energy in Bangladesh by reviewing literature and design a 50 MW solar power plant considering Bangladeshi situations.
- PV system configuration (amount of PV modules, tilt angle, inverter count, and interconnection between them)
- Electricity generated by the photovoltaic system

1.3 Limitations

There are few challenges need to be considered before planning a solar power plant. Finding suitable land for solar projects is difficult because most of the land in Bangladesh is agricultural land that cannot be used for renewable projects. Another major issue with renewable energy projects is that they are poorly planned because sunlight is a variable source of energy. The weather is the most important factor.

1.4 Status and prospects of energy sources in Bangladesh

1.4.1 Available energy sources

The primary energy resources in Bangladesh include natural gas, liquefied gas, coal, biomass and biofuel, hydro energy, wind energy, and solar energy. Therefore, natural gas with 2725 million cubic feet, condensate with 9263.7 million cubic feet, and coal with 345751.44 metric tons are produced in the fiscal year 2015-16. Energy consumption from different types is shown in Figure 1 in which natural gas accounts for 65 percent, heavy fuel oil for 18 percent, high-speed diesel for 7 percent, power imports for 5 percent, coal for 2 percent, and renewable energy for 3%. [4]

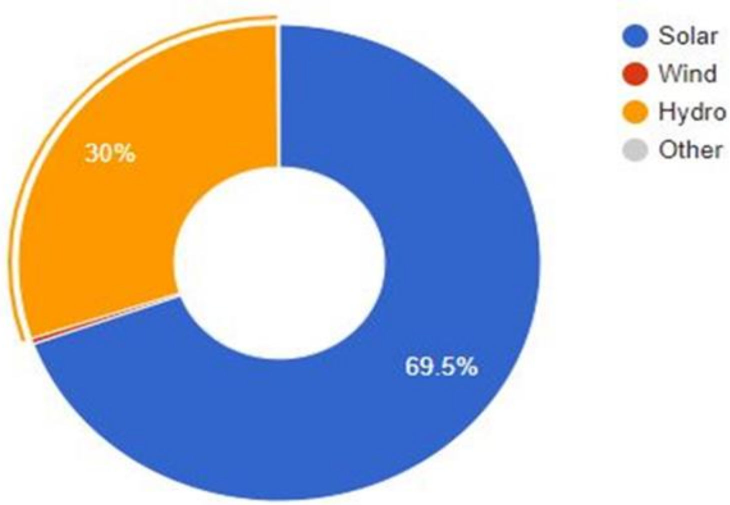

Fig 1: Share of Available Energy Sources [4]

1.4.2 Renewable energy sources

Bangladesh has a rich history of renewable energy, as the first hydroelectric project started in 1957 on the Karnaphuli River in Captain, Chittagong [4]. Currently, the various types of renewable energy used in Bangladesh include hydroelectric power, solar power, wind power, biomass, and bio-gas from the cows. Also, rooster dung from household waste and industrial process residues of bran and sugar canes are being used for electricity generation and heat production. Figure 2 shows the renewable energy share. It can be seen that solar energy has the highest potential among all and can be used for large-scale and long-term projects. [5]

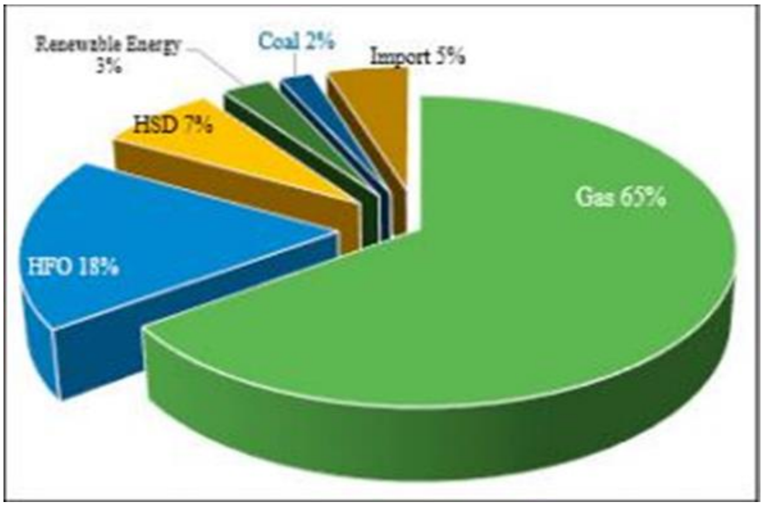

Fig 2: Share of Renewable Energy Sources [6]

Table 1 presents the installed capacity of different renewable energy technologies in Bangladesh of which solar energy has the maximum contribution.

Table 1: The installed capacity of different renewable energy technologies [6]

Technology	Off-grid (MW)	On-grid (MW)	Total (MW)
Solar	346.7	185.92	532.62
Wind	2	0.90	2.90
Hydro	0	230	230
Biogas to electricity	0.69	0	0.69
Biomass to electricity	0.40	0	0.40
Total	301	304	766.61

Chapter 2

Theoretical framework

2.1 Solar energy

The output of a solar plant depends on the amount of solar radiation incident on it. The power density perpendicular to the sun's radiation is 1365 W/m2 outside the earth's atmosphere, which is considered the "solar constant". Depending on the size of the atmospheric path and the amount of dirt, water vapour, ozone, CO2, and different aerosols gases, some of the photovoltaic radiation passing through the atmosphere will be scattered and absorbed. The industry has adopted common values to evaluate photovoltaic modules up to 1000 W/m2. However, the total amount of solar energy obtained daily in a particular neighbourhood is more important than the amount of photovoltaic radiation or the amount of instantaneous solar radiation. Solar energy assets are not equally available throughout the world, so all projects should evaluate the usefulness of the photovoltaic project accordingly.

2.2 Solar energy potential

Bangladesh is a place where 5 kWh/m2 of photovoltaic radiation is received 300 days a year. Maximum radiations can be used in March, April, and at least December and January. According to a 2012 study, each day daylight for Bangladesh is 7-10 hours. To account for rains, clouds, and fog, they cut the time in half (in 4.6 hrs) [4]. Therefore, this considerable photovoltaic power is possible to be able to limit the consumption of fossil fuel-based electrical generation for future generations. Figure 3 depicts a map of global horizontal irradiation[7]which determines the solar potential of Bangladesh. [5]

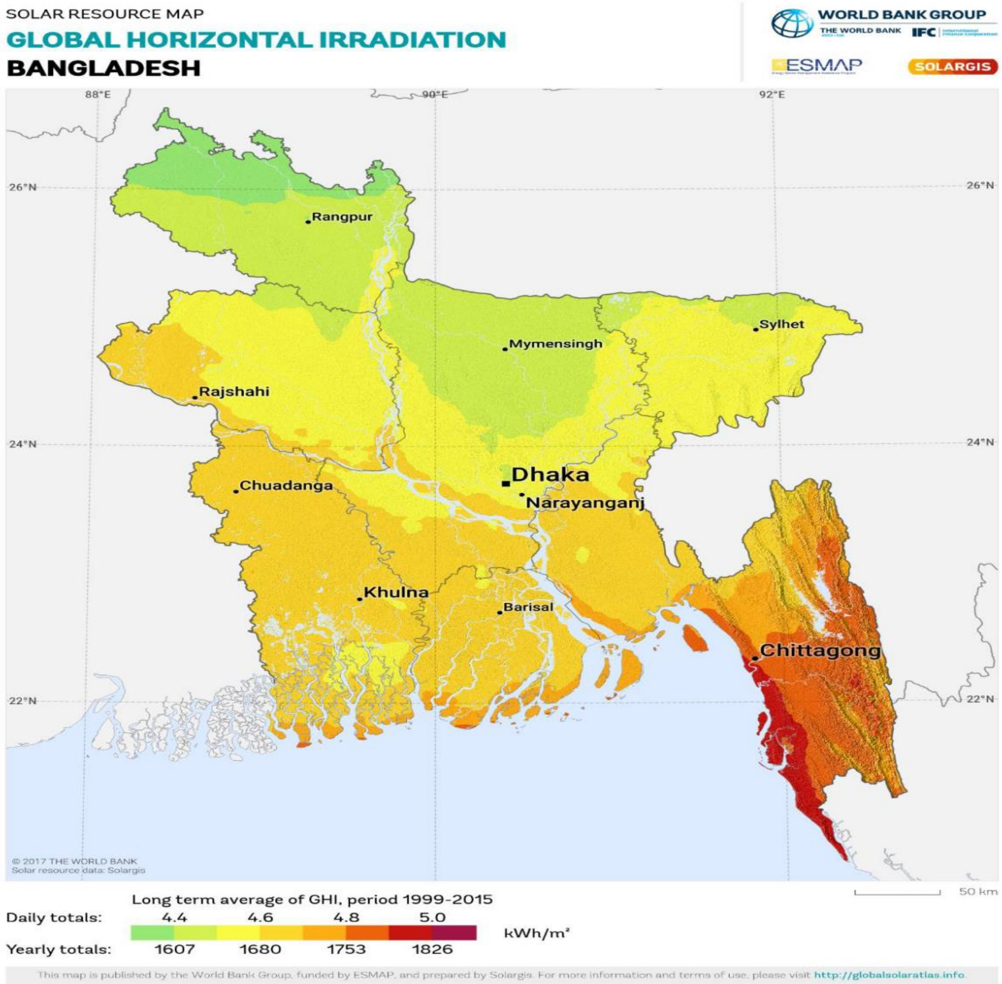

Fig 3: Global horizontal irradiation map [5]

2.3 Solar radiation profile (captured using PV)

As a tropical country, Bangladesh is fortunate with adequate sunshine in most areas and a variety of clear bright days throughout the year. In the north-eastern and hilly parts, daily common radiation is approximately 4.6 kWh/m2, whereas, in the western and desert areas, it is around 5 kWh/m2. In most parts of the country, sunlight hours range from 2200 to 2900 each year. The sun shines around 300 days a year in clear sunny weather [7]. Total yearly radiation ranges from 1300 to 1900 kWh/m2. The worldwide photovoltaic radiation map of Bangladesh, created jointly by MNRE and NREL, is illustrated in Figure 4.

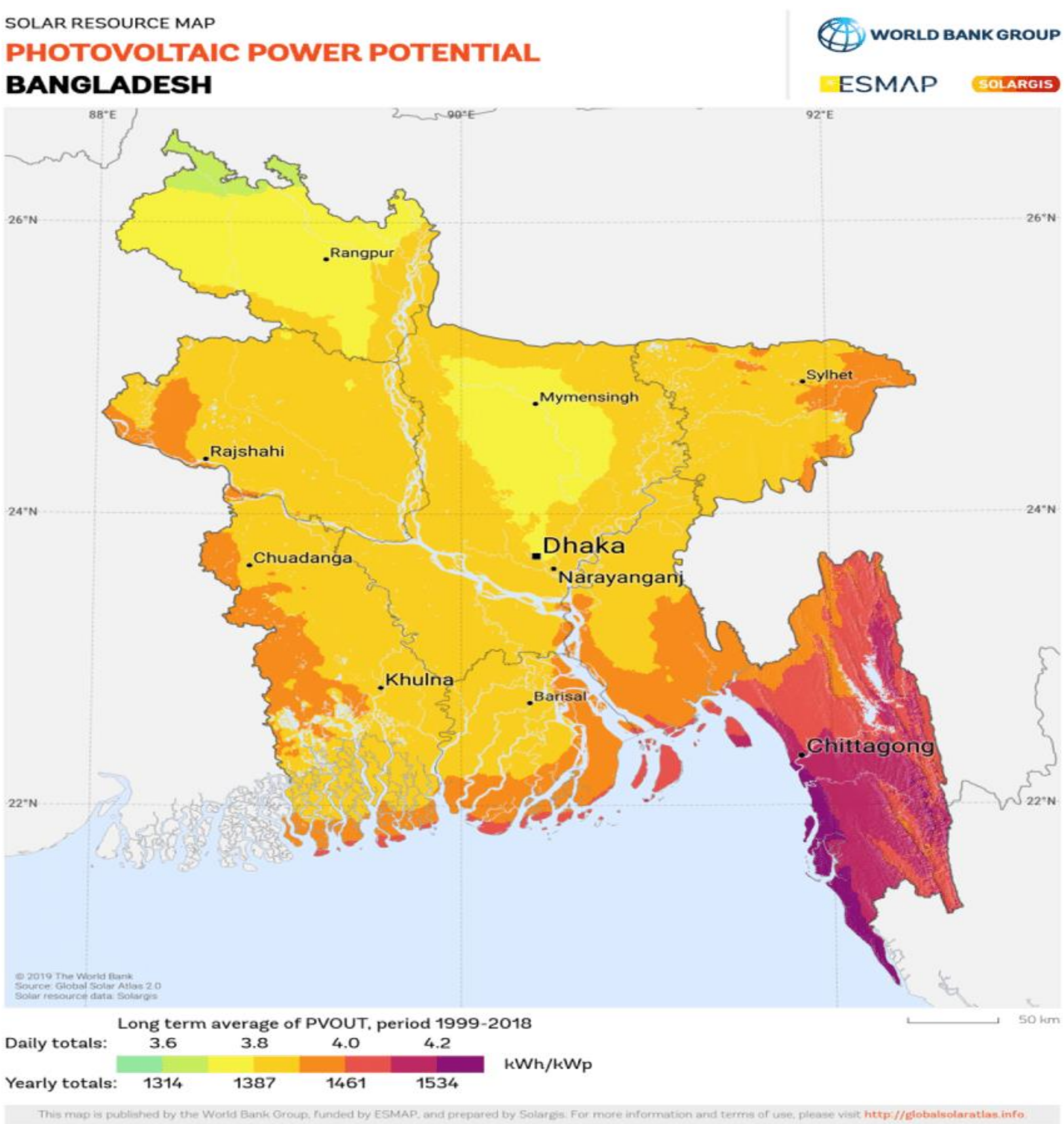

Fig 4: Global photovoltaic radiation map [9]

2.4 Components of photovoltaic power plant

This section describes the key components that make up a large PV plant. The components listed below are considered throughout the calculations used in the system's design. PV modules, inverters, transformers, switchgear, AC, and DC cables are the fundamental components. Following Figure 5 is the diagram of the arrangement used for the proposed strategy [10]

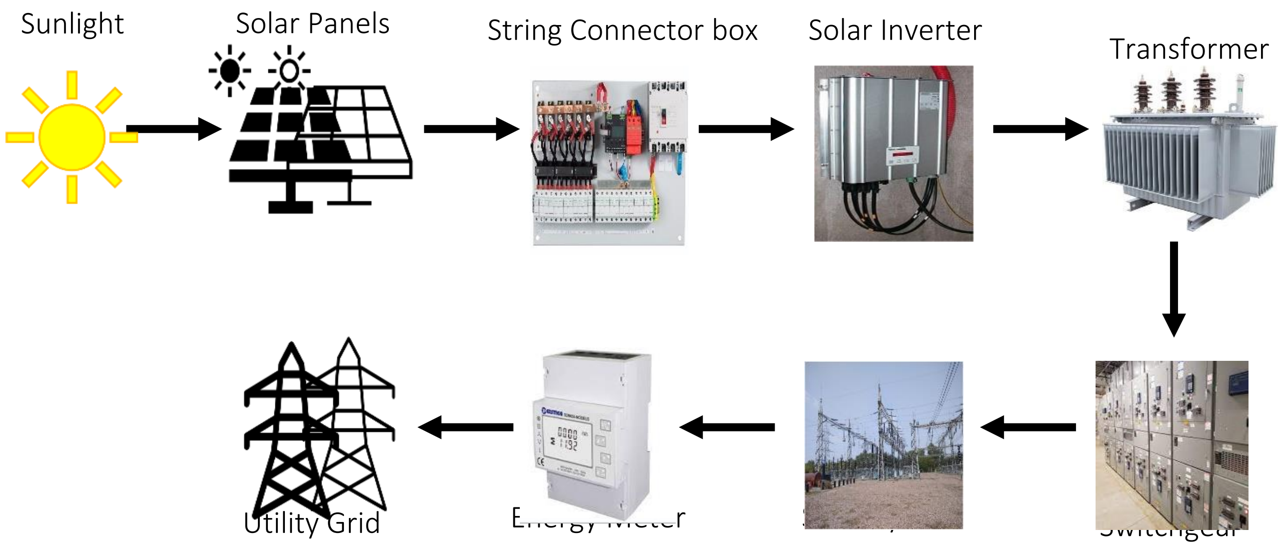

Fig 5: Block Diagram of PV plant [10]

2.4.1 PV array

The solar radiation incident on the panels is transformed to DC electricity, whilst the array of panels is built up by series and parallel connections. PV cells used in panels are mainly made of silicon semiconductor materials [11] Semiconductors are ideal materials for producing energy in solar cells because their electronic band gap allows free electrons, liberated by absorption of light, to persist in their excited state long enough to be collected to an external circuit. N-type and P-type semiconductor layers form a p-n junction that channels the electron flow in one direction, resulting in a direct current. Solar cell manufacturing technology is divided into three categories.

- Single crystal

  A cylindrical, single-crystalline silicon ingot is sliced into square wafers. Improved performance and high productivity are the results of this process. Monocrystalline cells are 18-22%efficient, perform well in low light, and have the greatest lifetime. However, these panels have the highest cost of all solar cells.

- Polycrystalline

  As a lower-cost option, polycrystalline silicon cells are produced by heating raw silicon in a mould, then cooling slowly to create a uniform rectangle wafer. Although the performance of this manufacturing process is lower than that of monocrystalline solar panels with an efficiency of 16-19%, however, it is cost-effective and simpler.

- Thin-film solar cell

  To make a thin-film solar panel, a thin layer of photovoltaic material is placed on the substrate. The efficiency of thin-film modules (e.g., CdTe) is up to 18 percent, according to the First Solar manufacturer. They are manufactured due to the simplicity of mass production, space efficiency, and manufacturing flexibility. Thin-film solar cells have not reached the same economies of scale compared to silicon and are still relatively more expensive per Wp.

2.4.2 The mounting structure

PV modules are fixed to the ground using mounting devices while considering the important parameters such as tilt angle, irradiance, shadow, and temperature. The basic assembly is fixed to the ground directly or embedded in concrete using concrete slabs or pouring shoes.

2.4.3 Inverter

With the help of an inverter, the direct current generated by the PV module is transformed into an alternating current. Because the inverter serves as a link between the grid and the PV system, so its output must comply with grid voltage, frequency, and energy limitations. The DC from a solar cell is split up into equidistant parts forming a square wave. A Fourier series evaluation of the developed square wave displays a mixture of sine waves known as harmonics. These harmonics are filtered using a digital system called a choke. A choke is an inductor that reduces high-frequency impulses while allowing low-frequency signals to flow through. Next, the output sign is smoothed and distinctive sinusoidal is obtained via series of electronic filters. There are several types of PV inverter systems, labelled as follows, relying on their operation.

- Standalone inverter
  The off-grid type consists particularly of PV grids, battery storage units, and inverters. DC output of the PV panel goes to the battery, where it is converted to AC via an inverter before sending it to the load.
- Grid-connected inverter
  This type of inverter is designed to work in parallel with the electric grid. The PV system's DC output is sent directly to the inverter, and the AC output is fed straight to the grid, where it may be used instantly by using the load or store surplus power in the storage device at midday. This type of gadget works as a massive pool of energy where the utility grid can either save or furnish power on demand. And this is done by the usage of a net metering device that considers the electricity saved and provided on the grid.

2.4.4 Transformer

A transformer on a solar power plant is mainly used to step up the voltage to deliver the power obtained by the means of the inverter to the utility grid. The design of the PV system can additionally reduce the number of transformers.

2.4.5 Switching equipment

Protection devices such as circuit breakers and relays can be found here. They not only safeguard the system but also ensure that the grid and PV panels are always connected.

2.4.6 Meter and other equipment

Meters are used to measure the energy consumed by the PV plant and fed into the utility grid. Whereas filters and converters can be used to improve system performance.

2.5 Types of design

2.5.1 DC system design

The DC design of the PV system includes the following components. All system components must be designed according to NEC code and utility requirements.

- Array sizing
- PV module arrangement
- DC cabling (wire size, module, and main cable)
- DC connectors and Combiner boxes
- Switches/disconnects
- Protective devices
- Ear thing

2.5.2 AC system design

The design of AC system made of [2]

- Size and placement of the inverter
- AC cabling
- AC switchgear
- Selecting transformer
- Protective devices
- Plant monitoring

2.6 Site selection

The site selection depends upon the factors given below which should be considered while designing the PV system.

2.6.1 Area

The area required depends on many factors, including the technology chosen for the PV module, the space required for cleaning and maintenance, and the space between arrays. The latitude of the location affects local decision-making [10]

2.6.2 Climate

Three different climate zones in the southern and northern hemispheres exists shown in Figure 6 [12]. The risk of damage due to certain climate situations should be kept low for a solar system. High wind speeds, flooding, air pollution, and high temperatures can damage the system and reduce its efficiency. The system would be designed with these in mind. E.g., if you expect strong winds, the mounting structures must be built to tolerate that. Snow does not necessarily cause damage. Again, the right modules will tolerate it.

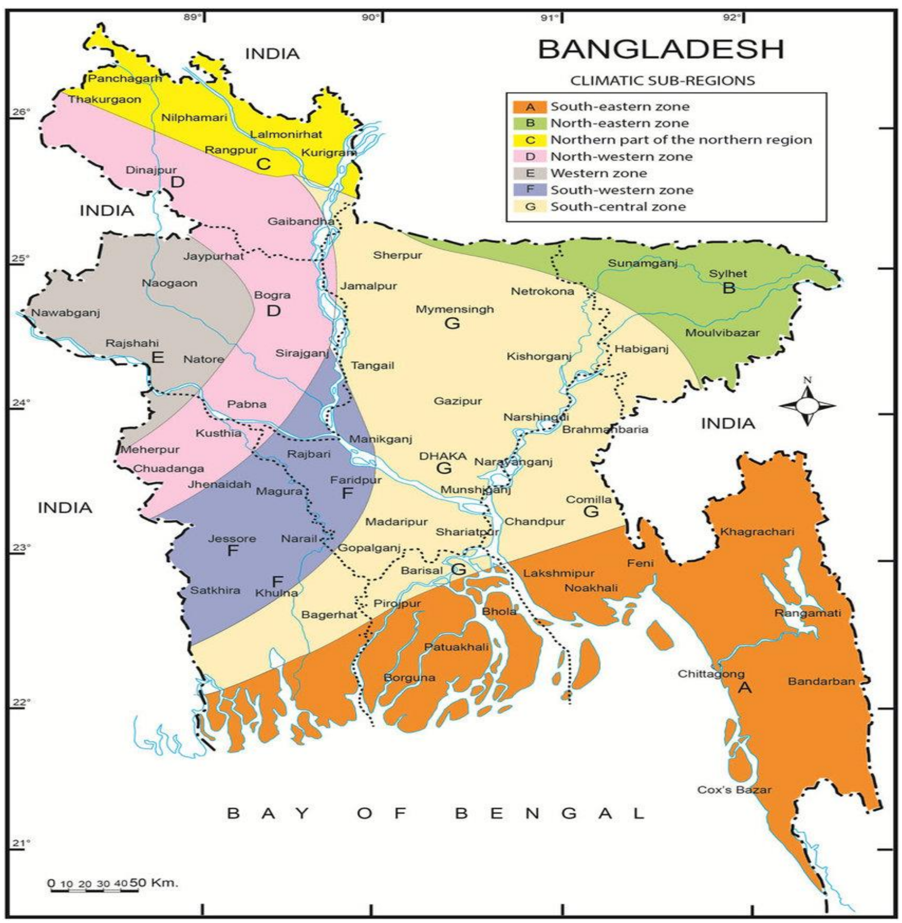

Fig 6: Climate zone map of Bangladesh [12]

2.6.3 Direction

In the Northern Hemisphere, the optimum slope to install a PV system is facing south, whereas, in the Southern Hemisphere, the best slope to install a PV system is facing north.

2.6.4 Land cost

Large-scale PV panels are often installed in less expensive lands. The cost of buying or renting the land should be included if the land is not owned by the solar system owner. This parameter participates in the calculation of LCOE.

2.6.5 Tilt angle

The best tilt angle for each location is the tilt angle that maximizes the total annual irradiance. For fixed installations of solar systems, this tilt depends on the latitude and can be determined generally or using some simulation software. A higher tilt angle can reduce dust accumulation. On the other hand, a highly tilted module will cast more shadows on the rear module, resulting in lower output. The inclination angle used for the simulation in this study is within a range of 50 to 400 [13]

2.6.6 Distance

The shading loss can be reduced by increasing the row spacing, but the required area will also increase, resulting in higher land costs. So, it is necessary to make a compromise between output and cost [14]

2.6.7 LCOE

Localized cost of energy refers to the cost of solar energy during the life of the system, considering the cost of components, land, operation, maintenance, construction, taxation, insurance, and other financial parameters. There is an effect of varying tilt angles on annual energy production and LCOE [15]

2.7 Solar recourse assessment

The term "Solar Resource Assessment (SRA)" refers to an examination of a potential solar energy production site to determine an accurate estimate of the facility's yearly energy production (AEP). As the manufacturer, designer, and supplier of measuring equipment employed, try to achieve this aim. [16]

2.7.1 Site location

The preferred photovoltaic park is placed Savar, about 15 kilometres south. The site is strategically located between the predominantly industrial areas. It is selected because it receives high solar irradiance and is close to power substations which reduce the cost of energy transmission. All the details and measurements of the geographical location are given below.

Geographical site

- Dhaka, Bangladesh
- Latitude: 23.71N
- Longitude: 90.78E
- Altitude: 22m
- Time Zone: UTC+6
- Albedo: 0.2
- Metro Data NREL NSRDB Typ. Met. Year Suny_2000 to 2014 – TMY

2.7.2 Meteorological data

When assessing a site for a Solar PV system, the quantity of solar radiation, temperature, natural catastrophes, winds, and seasonal floods must all be considered. In certain areas, this means meteorological data. For example, the meteorological data in the USA, the data of NASA, the atmospheric science data centre, etc. can be found based on their respective sites of data. For more than a decade, solar radiation and other characteristics have been monitored and are available on various government websites.

2.7.3 Radiation Profile of the Site (Bangladesh)

Solar radiation records can be accumulated from many sources like NASA-SSE, three Tier, Solar GIS, and METRONORM. METRONORM statistics is considering for this study that it makes use of both satellite as well as climate station data nearest to the site, whereas other data providers rely entirely on satellite-derived data. The METEONORM database contains TMY files for photovoltaic and climatic characteristics for several Indian sites, based on both measured and estimated values. The software program allows you to use geographical factors to interpolate photovoltaic and meteorological information for any location. Average horizontal photovoltaic radiation at the website comes out to be 4.57 kWh/m2/day as per METRONORM data.

Chapter 3

Methodology

In this part, the calculation approach for obtaining design parameters, power results, plant-associated efficiency, and many key factors necessary for measuring plant performance has been validated. The calculations utilized in this task for designing a PV solar power plant are entirely based on a paper that was published with the aid of Kerekes et al [17], where they propose a technique for the layout and optimization of large-scale PV systems in this paper.

3.1 Choosing technology

At the beginning of design, it is very important to select the technology which will be used in a 50 MW PV power plant. For choosing the technology three different simulations were performed for three scenarios in PVsyst by using the project location's solar radiation profile. In scenario 1 monocrystalline PV panels have been chosen and total system production was 81343 MWh/year. In scenario 2 polycrystalline PV panels have been chosen and total system production was 80587 MWh/year. In scenario 3 thin-film PV panels have been chosen and total system production was 82387 MWh/year. Thin-film technology is better for this project. The performance ratio is also higher for thin-film technology.

Table 2: Output for different PV technology

Scenario	PV Panel Technology	Inverter	System Production (MWh/year)	Performance ratio (%)
1	Monocrystalline	Sunny central 3000 UP	81343	83.5
2	polycrystalline	Sunny central 4000 UP	80587	82.71
3	Thin film	Sunny central 3000 UP	82387	84.6

3.2 Module selection

It is important to select the PV modules and get their specifications before beginning to apply the calculations for the PV plant design. The module First Solar Series 6 FS-4110-3 is selected for the PV plant design. The thin-film technology is a specialty of First Solar's manufacturer. The Series 6 modules are intended specifically for utility-scale power plants and to resist extreme weather. Table 3 lists the major features of these PV modules [18]

Table 3: Characteristics of proposed PV module

Parameters	Values
Type of technology	Thin-film CdTe
Dimensions	2009 x 1232 x 49mm
Weight	57kg
Maximum open circuit voltage	221V
Maximum short circuit current	2.57A
Peak power	450Wp
Module efficiency	18.2%

Selected thin solar panels have an advantage over other solar panels for several reasons:

- They are lightweight because of their construction where the panels are sandwiched between glass without a frame
- Cost less than traditional solar panels because they are easy to install and require less maintenance
- Have less of an impact on the environment because they use less silicon

See the technical datasheet for more information.

3.3 Number of modules

The overall number of PV panels required in the system, as well as the space necessary for the PV plant's implementation, will differ based on the module technology chosen for the PV plant. The following equation is used to calculate the needed number of PV panels (NPV):

$$N_{PV} = \frac{P_{design} \times 10^6}{P_m STC}$$

where, P_{design} is the power plant design capacity in MW and $P_m STC$ is the PV module power rating in W. The number of PV modules computed is merely an estimate based on the design capacity of the power plant; the final number of PV modules in the system are given in the system summary according to the area occupied by the PV modules.

3.4 Inverter selection

The inverter Sunny Central 3000-EVwas chosen for the PV plant design. Sungrow is one of China's leading inverter producers, with a market share of more than 40%. The chosen inverter is built for large-scale applications and has complete grid support. The major properties of the inverter are summarised in Table 4 [19]

Table 4: Characteristics of the proposed inverter

Parameters	Values
Type of inverter	Central inverter
Maximum input voltage	1500V
Maximum PV input current	2970A
Nominal output power	2160 kW (at 50 ºC)
Nominal AC voltage	771 V
Maximum inverter output current	2646 A
Maximum efficiency	98.8%
CEC efficiency	98.5%
Dimensions	2780 x 2318 x 1588 mm
Weight	3.4 T

Centrally installed inverters in a PV system offer many advantages over distributed inverters:

- Higher flexibility and suitability for larger PV plants.
- Smart service and operation.
- Faster installation and commissioning.
- Superior yield and performance ratio.

3.5 Number of inverters

After determining the total number of PV modules in the PV plant, the number of modules in series, and the number of modules in parallel, the number of inverters required in the system may be determined. This computation was done using the following formula:

$$N_i = ceil\left[N_{pv} \times P_{mod}\right]$$

where it is considered $N_i = number\ of\ inverters$ and $N_{PV} = number\ of\ modules.P_{mod}$ is the power of the module. The final number is produced by rounding the computation result to the greatest closest integer.

3.6 Inverter sizing

Solar irradiance and module tilt angle are essential factors to consider when choosing an appropriate inverter size because no one method fits all situations. When constructing an inverter, it is recommended that the inverter-to-array power ratio be less than one. For example, this decision might result in the inverter successfully reducing power spikes caused by an unexpected irradiance profile, or it could result in the inverter failing to comply with grid standards when reactive power injection is required. Most plants have inverter sizes that fall between the following ranges:

$$0.8 < power\ ratio < 1.2$$

The inverter is aided by system sizing software offered by manufacturers.

3.7 Configuration of PV modules

A PV module's configuration is determined by several elements, including the module's features, inverter, shading, and so on. When all factors are considered, putting PV modules in a horizontal arrangement is more cost-effective than placing them vertically.

3.7.1 Tilt Angle

All solar panels have an optimum tilt angle that maximizes power generation. However, due to the specific concerns described below, it may not be possible to set all panels to the optimum tilt angle.

- Pollution: Contamination loss due to dust particles, snow, and other debris accumulating on the PV panel. Rainwater will wash away dust and light can easily enter at higher tilt angles.
- Shadow effect: The larger the shadow cast by the panel, the greater the tilt angle. Therefore, panels placed in the shadows are inefficient and require adjustment of output.
- The amount of insolation varies depending on the season. During the rainy season, for example, the tilt angle can be adjusted by adjusting the mounting structure to compensate for the loss by blocking the sun's rays with clouds.

3.7.2 Spacing

Shade, manufacturing area, restricting wiring cable lines, and other factors all influence the distance between solar panels. However, it is nearly impossible to eliminate the shadows between columns. Though, this can be reduced by reducing the inclination angle. Designers also follow a rule of thumb to ensure that there is no shade at noon of the sun during the winter solstice. The plant is also considered appropriate if the annual loss due to shading is less than 1%.

3.8 System summary

System	Grid-connected System
Orientation	PV field Orientation
Tilt angle	Fixed 250
Azimuth angle	0°
Shadings	No
PV array	111108 modules
Pnom Total	50 MWp
No. Inverters	13 units
Pnom Total	39MWac
Pnom ratio	1.282

3.9 Project summary

Thin-film solar cells have been recognized as a feasible PV technology for the suggested location since they can perform well in Dhaka's meteorological and operational circumstances. To evaluate the best working tilt angle for the desired location, the computer software named PVsyst has been used.

Taking the geographic (latitude, longitude) and climatic parameters, the technical model is compared on different tilt angles. The estimation of the complete plant has been given in the system summary and parameter selection has been described earlier [20]. Here below is the project summary.

Geographical site	Dhaka Bangladesh
Latitude	23.710N
Longitude	90.780E
Altitude	22m
Time zone	0.20
Albedo	UTC+6

3.10 Software used: PVsyst

PVsyst V6.67 is a PC software program that allows you to research, size and analyse entire PV systems. It comprises substantial Meteo and PV systems components databases, as well as basic solar energy tools, and it handles grid-connected, stand-alone, and DC-grid (public transportation) PV systems [21][22]. PVsyst V6.67 provides three levels of PV system analysis, roughly correlating to the stages of project development:

- Preliminary design: this is the project's pre-sizing stage.
- Project design: utilizing comprehensive simulations, providing a thorough system design.
- Databases: Meteorological data and PV components are stored in databases.
- Tools: For analysing measured data

Chapter 4

Results and Analysis

4.1 Results

The proposed scheme designed using the calculation method is verified through the simulations on PVsyst. The experiment is performed on various tilt angles and their results have been compared in Table 5. It has been found that among any other tilt angle, 250proved to be the best optimal choice for the plant as it has the highest specific production. The performance ratio for tilt angle 230 is the highest but we must find the optimal solution considering every other factor.

Table 5: Comparison of energy produced and PR at different tilt angles

Tilt	Specific Production (kWh/kWp/yr.)	Produced Energy (MWh/yr.)	Normalized Production (kWh/kWp/day)	Performance Ratio (%)
50	1576	78805	4.32	84.76
230	1648	82380	4.51	84.61
250	1648	82387	4.51	84.59
270	1646	82316	4.51	84.57
400	1601	80052	4.39	84.53
Seasonal	1701	85043	4.66	84.41

4.1.1 COMPUTATIONAL RESULTS

Under the PVsyst software, the simulation model was built as a one-of-a-kind project. The meteo data were obtained using the program from Metronome 7.1, and the location was Dhaka, Bangladesh. The simulated data provided by the PVsyst for the setup is shown in Figure 7.There is a variation in response owing to the ever-changing movement of the sunbeams, even though a healthy average value is recorded throughout [23]

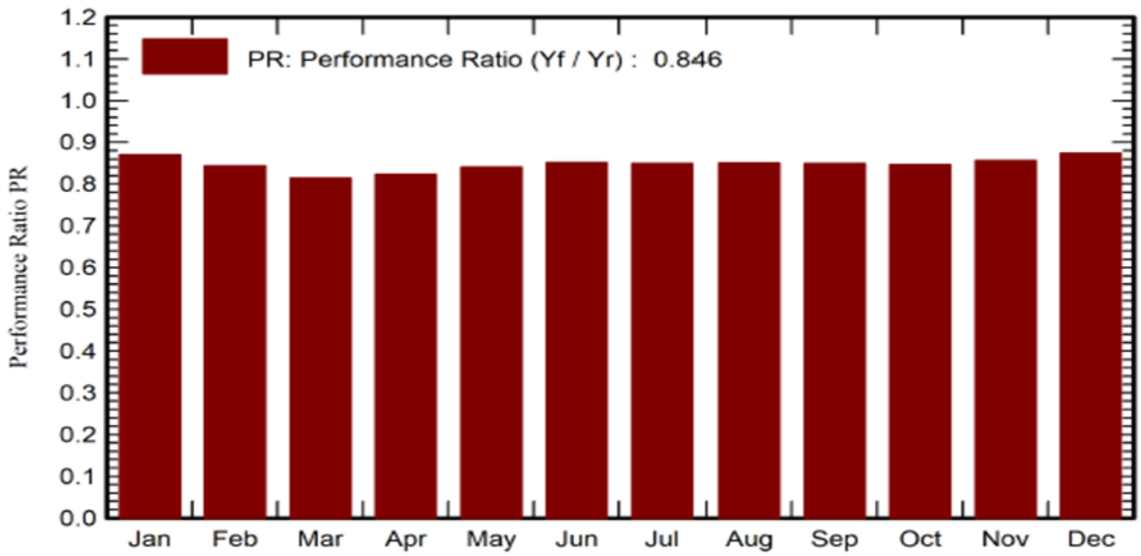

Fig 7: Performance Ratio PR for 25° tilt angles [23]

Because of its unique geographic location, the country is in a perfect location for capturing solar energy to its full potential. The normalized production and loss factors for the 50 MW power plant, which was rebuilt for simulations, are shown in Figures 8-9. The electricity production is well maintained for the whole year, system losses are quite negligible and conduction losses from the PV modules exists but still through our design strategy, the required production is achieved.

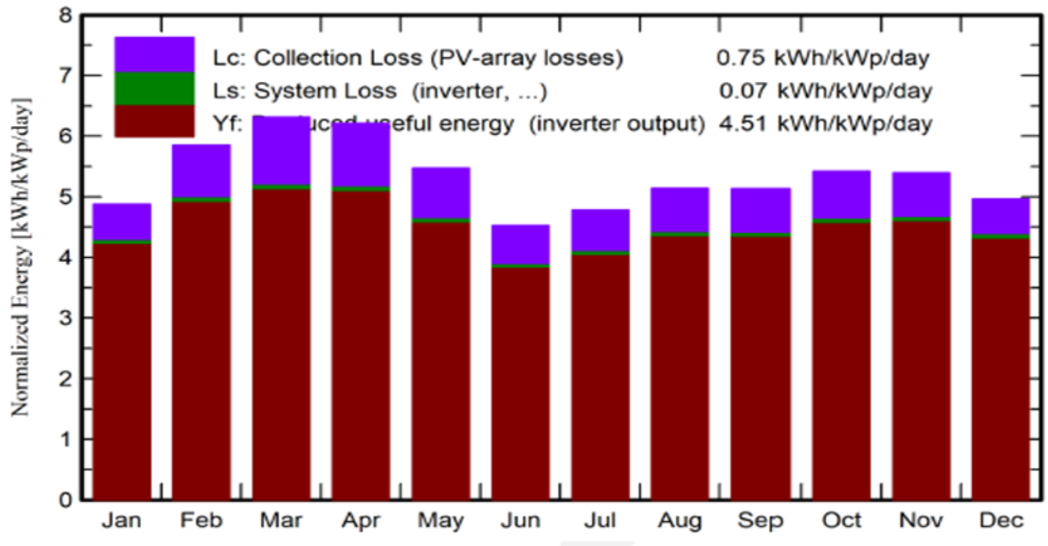

Fig 8: Normalized production (per installed kWp) for 25° tilt angles [23]

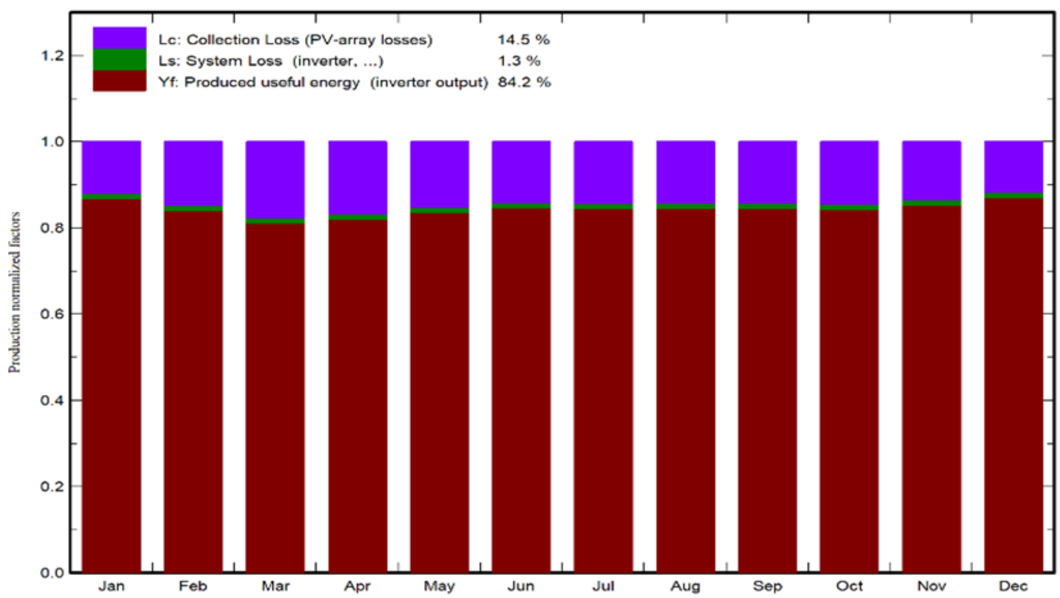

Fig 9: Normalized production and loss factors [23]

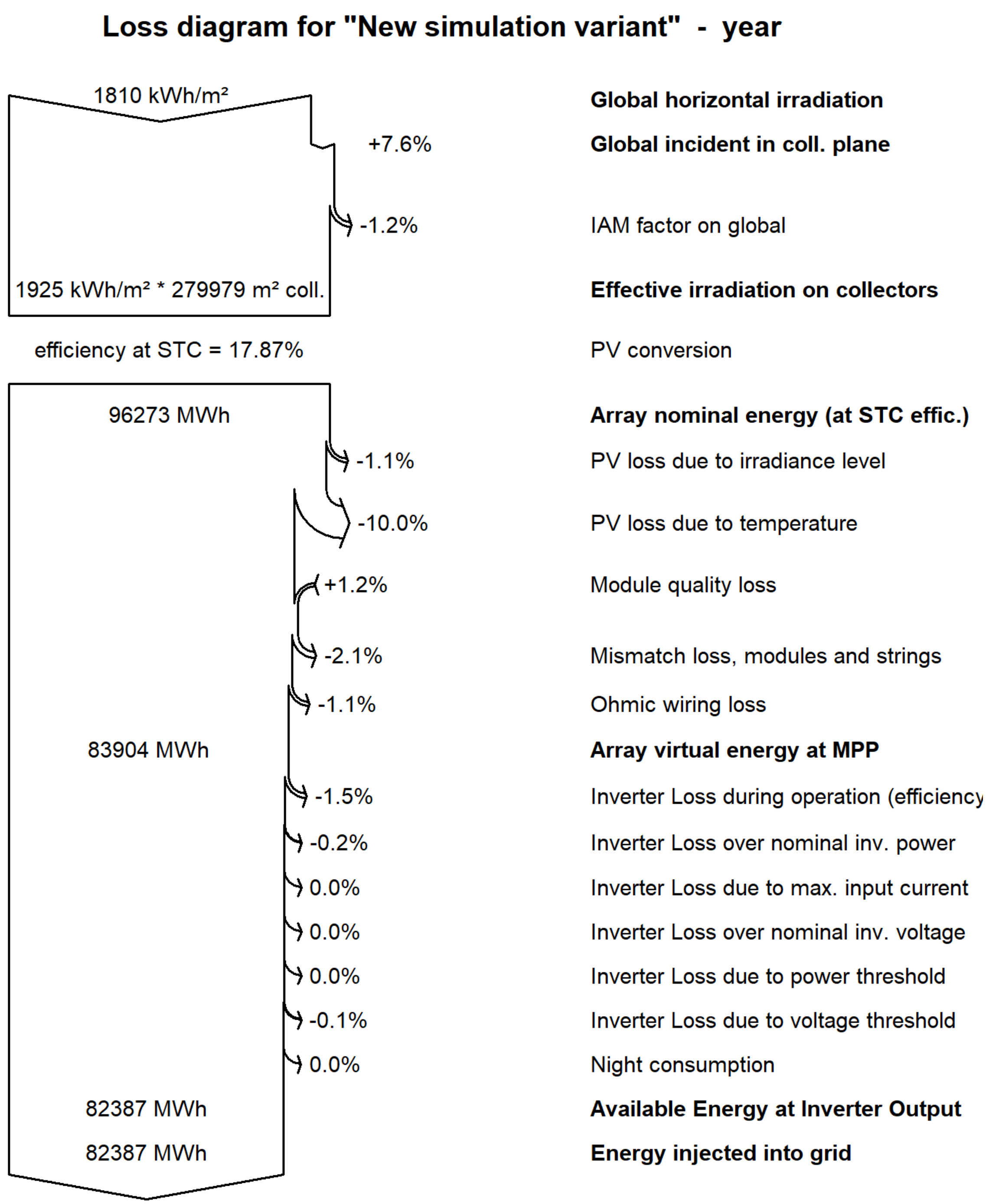

Fig 10: Loss diagram at25-degree tilt angles [23]

In Figure 10, we can see that the largest individual loss is from higher than optimal temperatures. TF modules have lower temperature coefficients than Si, so probably this would have been worse with Si modules. From the simulation results, the Figure 7-10 are developed. The results are summarized for various considerations in Table 6. The analysis was done with the help of reports based on their results.

Table 6: Comparison of incident radiations and energy produced at different tilt angles

Tilt	GlobalInc (kWh/m2)	GlobalEff (kWh/m2)	EArray (MWh)	E_Grid (MWh)
5°	1859.5	1830.7	80014	78805
23°	1947.3	1923.7	83651	82380
25°	1947.9	1924.5	83658	82387
27°	1946.7	1923.5	83586	82316
40°	1894.1	1870.1	81289	80052
Seasonal	2015.1	1992.6	86357	85043

Where GlobalInc is the global incident in collector plane, GlobalEff is Effective global, correspondence for Incident angle modifier (IAM) and shadings, EArray is Effective energy at the output of the array and EGrid is Energy injected into the grid. It is found that the 25-degree tilt angle receives the most radiation to produce the highest energy.

4.2 Performance analysis of the plant

There are certain different types of analysis are considered to prove the effectiveness of the system which include the following analysis:

- Performance analysis
- Financial analysis
- Economic analysis
- Environmental analysis

4.2.1 Performance ratio (PR)

PR is an index that measures the performance of a solar system after considering environmental factors such as temperature, radiation, and climate change. And usually expressed as a percentage. A higher PR means that the solar system converts more solar radiation into useful energy [14]

4.2.2 Specific energy yield

Specific energy yield is the total energy produced per kW of installed capacity in one year. It participates in LCOE calculations and is used to compare the performance of different technical systems. It is determined by the system's total yearly exposure, component efficiency, and system losses.

4.2.3 Shading

Dark conditions reduce the radiation received and cause energy loss therefore they should be minimized. Shadow losses are caused by different reasons, including distant trees, mountains, buildings, and selfshadows between rows of modules [15]. The full solar path diagram of the site location should be used to analyse the shadows.

In this study, the results for 250 tilt angles have the highest PR and specific yield and it is assumed that there is no shadow in the area, and the only shadow loss in the system is the shadow between the rows.

4.3 Financial analysis

Solar projects are complex that's why local private banks are very concerned about investing in them. Banks always looks forward to making a quick profit, but solar projects sometimes fail to fulfil their desire. The government is also excluding preferential funding for utility-scale projects.

The financial analysis is done by keeping the project lifetime to be 25 years with an inflation of 0.03% and an income tax rate of 12% per year. The time value of money is ignored throughout the payback period. The number of years it takes to repay the cash invested is used to calculate it. The payback period is almost 5.5 years for our proposed case. PV will never make a "quick" profit since almost all costs are up-front. You need to wait for the payback period to be over. After that, you can make a lot of profit. PV is a (very good) long-term investment.

After doing this analysis for various tilt angles, the net present value (NPV) and return on investment (ROI) are summarized in Table 7 which clearly shows that at the tilt angle 250, the ROI is highest [16][24]

Table 7: Comparison of NPV and ROI at different tilt angles

Tilt	NPV (USD)	ROI (%)
5°	94502288.27	329.8
23°	100393618.32	350.3
25°	100404941.29	350.4
27°	100287819.77	350
40°	96557604.88	337
Seasonal	104782042.49	365.7

4.4 Economic analysis

The goal of economic analysis is to guarantee that scarce resources are distributed properly, and that investment benefits a country and improves its inhabitants' well-being. It is a mechanism that the Asian Development Bank (ADB) uses to ensure that its activities adhere to its Charter [21][25][26][27]

The analysis includes the installation and operating costs for the Bangladesh site are given in Tables 8 and 9 respectively by keeping are the factors in mind [28]

4.4.1 Installation cost

The installation cost is categorized as:

Table 8: Installation cost

Components	Project Cost (In percent)
PV Modules	48%
Inverter	13%
Structure	5%
Installation	16%
Land	2%
O&P	2%
Others	14%
Total	100%

4.4.2 Operating cost

The operating cost is categories as:

Table 9: Operating cost

Items	Project Cost (In percent)
Maintenance	
Salaries	49%
Reparation	3.5%
Clearing	8.5%
Land rent	39%
Total	100%

When the system is tested for different tilt angles, it is found that the Global Investment is 28650000 USD,Specific Investment (USD/Wp) is 0.57, Run costs is 306100 USD/yrand LCOE is 0.02 USD/kWh but the payback period changes for every angle and the 250proved to be the best choice for the location with lower payback period.

Table 10: Comparison of payback period at different tilt angles

Tilt	5 °	23 °	25 °	27 °	40 °	Seasonal
Payback period (years)	5.8	5.6	5.5	5.6	5.7	5.4

4.5 Analysis of CO2 emissions

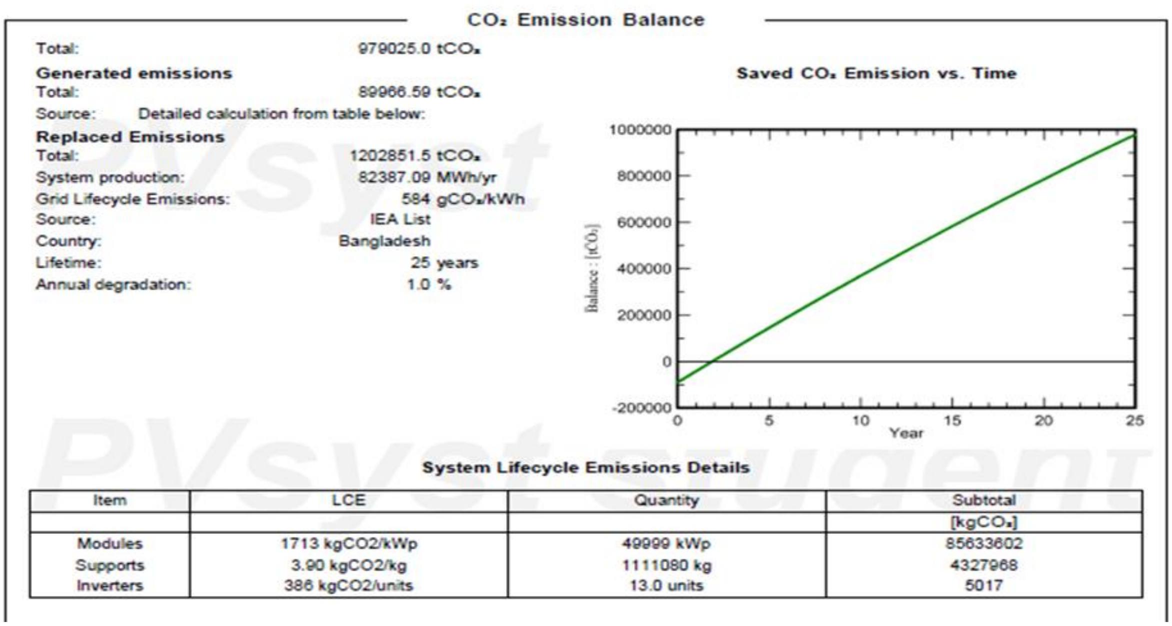

Fig 11: CO2 emission balance [29]

The traditional sources of energy production pollute our environment and contribute towards global warming. The use of renewable energy sources like PV plants reduced these GHG emissions. They save CO2 emissions because they do not use any toxic elements. The potential environmental analysis associated with solar power can vary greatly depending on the project size [29]. The CO2 emission balance is given in respective Figure 11. It shows the number of emissions generated by the PV plant is less than the number of emissions that the plant replaced which were present earlier. The generated emissions from the plant are mainly produced during the manufacturing process of panels. Other contributing factors are the transportation and installation of these panels. Hence, solar panels are assumed to be environmentally friendly sources of energy.

The 25° is the best optimal tilt angle as it replaced the maximum of the carbon emissions as seen from Table 11 on comparison from other angles.

Table 11: Replaced Emissions for various tilt angles

Tilt	Replaced Emissions (tCOx)
5°	1150552.8
23°	1202751.1
25°	1202851.5
27°	1201813.8
40°	1168762.2
Seasonal	1241633.5

Chapter 5

Discussion

This undertaking is for the development of a 50 MW sunlight based photovoltaic force plant utilizing the latest Thin Film Technology cells. The optimal tilt angle has been determined to be 25 degrees. The energy output from this project is 82387 MWh per year, with a payback time of 5.5 years and a reduction in CO_2 pollution of 1202851.5 tonnes per year. If we increase the tilt angle the row spacing will be high and it will increase the project cost. The payback period is also high for other tilt angle. This type of solar project will reduce the CO_2 emissions as well as reduce the fossil fuel dependency.

There are lots of challenges also for these types of projects. As most of the land in Bangladesh is agricultural land that can't be used for renewable projects so it's a big challenge to find suitable land for solar projects. Whenever there is any land available, it has a shortage of major facilities. So, it is challenging to come across an appropriate location for the installation of the system. Another main issue about renewable energy projects is that they are not well planned as sunlight is the intermittent source of energy. It depends primarily on weather conditions. Also, electricity transmission infrastructure has to be improved to use this source of green energy. The assessment for potential sites for renewable energy in terms of transmission capacity is limited. The study for national grid capacity can't be done properly as we cannot predict the future of generation properly. Grid code requirements and grid integration are important for a renewable plant. All the studies should be done accurately to get the best possible result [30]

Chapter 6

Conclusions

Solar power is an infinite, accessible, and environmentally friendly source of renewable energy with massive output. The analysis of peculiar topologies of PV systems provides a better knowledge of selecting for advanced design. Issues discussed in designing the system will assist in selecting solar power plant construction. In this study, a framework has been developed to optimize the tilt angle and pitch distance in massive scale PV plants. The regarded criterion for optimization is the least LCOE and the effect of exceptional climate conditions for various considerations has been investigated. In this study, Savar, about 15 kilometres south is chosen for testing different tilt angles which cover diverse climate variations. The focal point is an impact of tilt angle, so the type and variety of elements used were kept the same in all cases for the selected site. The simulations are executed for various tilt angles in the PVsyst program and then compared to get the optimal result. The economic analysis is done in each condition to get the LCOE and produced electricity which provides full analysis and support for PV system installation. At the last, the tilt angle which leads to the least LCOE is determined by comparing the result for the range between 50 and 400. Moreover, the financial parameters had been assumed consistent for all variations to acquire the best results. In conclusion, the principal findings of this study can be summarized for tilt angle 250 as the most effective angle.

Chapter 7

Future work

The research work described here may be applied to a wide range of aspects and climatic conditions. For example, the effectively stages of a PV system largely rely on limiting PV losses, temperature increase, mismatch losses, and other factors that would improve PV device performance. Lastly, the local government can help large-scale solar device buyers through incentives and support mechanisms that would enhance solar power generation.

The following areas should be considered while approaching towards future studies and work related to the solar panels and energy generation

- Researchers should try to get the solar panels as efficient as possible. Work should be done on trying to increase the efficiency of the panel cells.
- If we consider power tower technologies, efforts should be made in order to find more suitable liquids that have high capacities.
- Material science researches should try to manufacture or explore products that can help reduce the cost and risks related to these solar panels.
- Researches should work and find a way to store the excess solar energy so that we can lessen the use of toxic fossil fuels and decrease the power generation cost of the world.
- Development is needed in the areas of PV applications such as metal-air batteries, flywheels, capacitors, and super capacitors which have a very bright future.
- The thermal energy storage systems need to have a backup for the long term storage.

Chapter 8

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